JACC: CARDIOVASCULAR IMAGING VOL. 4, NO. 2, 2011
© 2011 BY THE AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION
ISSN 1936-878X/$36.00
PUBLISHED BY ELSEVIER INC. DOI:10.1016/j.jcmg.2010.11.013

Noninvasive Evaluation of Coronary Reperfusion by CT Angiography in Patients With STEMI

Makoto Yamashita, MD,* Souki Lee, MD,* Shuichi Hamasaki, MD,†
Tatsuya Nishimoto, RT,‡ Takashi Kajiya, MD,* Koichi Toyonaga, MD,*
Ryoichi Arima, MD,* Hitoshi Toda, MD,* Ichiro Ohba, MD,† Yutaka Otsuji, MD,§
Chuwa Tei, MD†

Kagoshima and Kitakyushu, Japan

OBJECTIVES The aim of this study was to determine whether 64-slice multidetector computed tomography (MDCT) can differentiate coronary reperfusion with Thrombolysis In Myocardial Infarction (TIMI) flow grade 3 from TIMI flow grade ≤2 after ST-segment elevation myocardial infarction (STEMI).

BACKGROUND Multidetector computed tomography has become a popular modality for noninvasive coronary artery imaging. Recently, 64-slice MDCT has been applied to evaluate coronary arteries in acute coronary artery disease.

METHODS The presence or absence of distal reperfusion in infarct-related arteries (IRA) was visualized with 64-slice MDCT during the acute phase in 87 non– high-risk patients after STEMI. To differentiate TIMI flow grade 3 from TIMI flow grade 2, we calculated the computed tomography (CT) number ratio by dividing the CT number of the contrast-enhanced coronary lumen at the most distal IRA by that at the proximal site to the culprit lesion in patients with reperfusion on MDCT. The MDCT findings were compared with TIMI flow grade with invasive coronary angiography (ICA) performed 20 ± 5 min later.

RESULTS According to ICA, 58 patients had TIMI flow grade 0 or 1, 17 had TIMI flow grade 2, and 12 had TIMI flow grade 3, whereas distal reperfusion was evident on MDCT in 28 of the 29 patients with TIMI flow grade ≥2 and absent in 55 of the 58 with TIMI flow grade ≤1. The CT number ratio was significantly higher in TIMI flow grade 3 than in TIMI flow grade ≤2 (0.64 ± 0.11 vs. 0.37 ± 0.12; $p < 0.0001$). The sensitivity, specificity, and accuracy of a diagnosis of TIMI flow grade 3 on the basis of a CT number ratio of ≥0.54 that was an optimal cutoff value determined by receiver-operator characteristic curve analysis were 92%, 97%, and 97%, respectively.

CONCLUSIONS Visualization of the IRA by 64-slice MDCT enables noninvasive differentiation of angiographic TIMI flow grade 3 from TIMI flow grade ≤2 coronary reperfusion during the acute phase in patients with STEMI. (J Am Coll Cardiol Img 2011;4:141–9) © 2011 by the American College of Cardiology Foundation

---

From the *Department of Cardiology, Kagoshima City Hospital, Kagoshima, Japan; †Departments of Cardiovascular, Respiratory, and Metabolic Medicine, Graduate School of Medicine, Kagoshima University, Kagoshima, Japan; ‡Radiological Technology, Kagoshima City Hospital, Kagoshima, Japan; and the §Second Department of Internal Medicine, School of Medicine, University of Occupational and Environmental Health, Kitakyushu, Japan. The authors have reported that they have no relationships to disclose.

Manuscript received August 23, 2010; revised manuscript received November 22, 2010, accepted November 24, 2010.

Suboptimal coronary reperfusion with Thrombolysis In Myocardial Infarction (TIMI) (1) flow grade ≤2 in acute ST-segment elevation myocardial infarction (STEMI) adversely affects prognosis (2) and requires additional procedures, such as thrombolysis and/or percutaneous coronary intervention (PCI). The gold standard for investigating coronary reperfusion after STEMI is invasive coronary angiography (ICA), and thus a noninvasive method of diagnosing coronary reperfusion is desirable. Although current noninvasive tools that can evaluate coronary reperfusion—including the resolution of ST-segment elevation by electrocardiography (ECG) (3), the rapid washout of serum cardiac biomarkers (4), and the preservation of coronary flow velocity by transthoracic Doppler echocardiography (5)—are accurate, each of these methods has limitations, because they are indirect and cannot visualize the entire distal part of the infarct-related artery (IRA).

ABBREVIATIONS AND ACRONYMS

CT = computed tomography

ECG = electrocardiography

HU = Hounsfield units

ICA = invasive coronary angiography

IRA = infarct-related artery

MDCT = multidetector computed tomography

PCI = percutaneous coronary intervention

ROC = receiver-operator characteristic

ROI = region of interest

STEMI = ST-segment elevation myocardial infarction

TIMI = Thrombolysis In Myocardial Infarction

Multidetector computed tomography (MDCT) has recently become a popular modality for noninvasive coronary artery imaging (6–10). Recent technical advances in MDCT, particularly 64-slice MDCT, have enhanced image quality by improving spatial and temporal resolution (7–10). In addition, these advances have enabled rapid scanning of the cardiac anatomy, thereby reducing the burden imposed on patients, including a short breath-hold as well as reductions in contrast medium and radiation doses. Consequently, 64-slice MDCT can be applied to noninvasively evaluate coronary arteries in acute coronary artery disease (7–9). Several recent studies (7,8) have demonstrated that 64-slice MDCT can rule out acute coronary syndrome in individuals with possible myocardial ischemia. Thus, MDCT could potentially be used to safely and noninvasively evaluate reperfused coronary arteries during the acute phase after STEMI. Although coronary blood flow in both TIMI flow grades 2 and 3 reperfuses angiographically to the distal site of an IRA, distal coronary flow velocity and flow volume are reduced in TIMI flow grade 2 compared with TIMI flow grade 3 reperfusion (5,11,12), which can be expressed as attenuated contrast visualization of the distal IRA in TIMI flow grade 2 by coronary MDCT.

Therefore, we hypothesized that 64-slice MDCT could visualize the presence or absence of distal coronary reperfusion in patients soon after STEMI and that differences in coronary blood flow between TIMI flow grades 2 and 3 could be detected as differences in contrast visualization in the distal IRA by MDCT, which would enable noninvasive differentiation between these 2 flow grades. Because the feasibility of 64-slice MDCT to evaluate coronary reperfusion has not been fully investigated, the present study tested these hypotheses by comparing the 64-slice MDCT findings from an IRA with those of the ICA during the acute phase in non–high-risk patients with STEMI.

METHODS

Study population. We analyzed data from 110 consecutive patients with a first STEMI and without a history of surgical revascularization. The inclusion criteria comprised: 1) typical chest pain lasting for ≥30 min and ≤12 h from symptom onset; 2) ST-segment elevation of >0.2 mV in ≥2 contiguous ECG leads; and 3) increased cardiac enzymes (subsequent increase in serum creatine kinase ≥2-fold the upper limit of normal). We excluded 10 patients because of a high risk of STEMI, such as Killip classification ≥2 (13). Thirteen others were excluded from this study, because of inability to follow breath-hold commands (n = 2), baseline renal insufficiency (creatinine levels ≥1.5 mg/dl; n = 3), atrial fibrillation or severe arrhythmia (n = 3), and visually severe calcification of the IRA on unenhanced MDCT (n = 5). We finally recruited 87 patients for the present study. The Institutional Committee of Kagoshima City Hospital approved the study protocol, and all patients provided written informed consent to participate before enrollment.

Study protocol. Soon after primary treatment for STEMI and echocardiography in the emergency department, all patients were administered oral aspirin (162 mg) and then evaluated by emergency MDCT and subsequent ICA. Fibrinolysis was performed before the MDCT study in 12 patients but not between the emergent MDCT and ICA.

MDCT data acquisition. All MDCT examinations were performed with a 64-slice computed tomography (CT) scanner (Aquilion, Toshiba Medical Systems, Otawara, Japan). The position of the coronary arteries and the coronary calcium burden were assessed in all patients by noncontrast scanning before MDCT angiography. A contrast-enhanced study then proceeded with retrospective ECG gating with the following angiographic scan parameters: detector collimation, 0.5 × 64 mm; gantry rotation time, 350 ms; table feed, pitch factor 0.17; tube current, 250 to 450 mA, and tube voltage, 120 kV. The reconstruction kernel used FC14. All patients breathed oxygen during the MDCT examinations and received 0.3 mg of sublingual nitroglycerin. A beta-blocker (propranolol hydrochloride, 2 to 6 mg) was administered intravenously when heart rate reached >65 beats/min and no contraindications were present. Heart rates that fell to <40 beats/min were increased with atropine. A bolus of 55 to 70 ml of nonionic contrast material (Iohexol 350, Daiichi-Sankyo, Tokyo, Japan) was injected through an antecubital vein at a flow rate of 4 to 5 ml/s followed by 40 ml of saline chaser. Scanning was synchronized with the arrival of contrast in the coronary arteries with a bolus-tracking technique, and then scanning was started when contrast attenuation in a selected region of interest (ROI) in the ascending aorta reached a defined threshold of +120 Hounsfield units (HU). All images were acquired while holding an inspiratory breath for approximately 10 to 12 s. Two cardiologists attended to ensure patient safety during all MDCT examinations.

MDCT data analysis. Two independent, experienced observers who were blinded to the results of the quantitative coronary angiography analyzed the CT datasets. Differences in interpretation were resolved by consensus or by a third investigator if necessary. All data were evaluated with an online workstation with dedicated software (Ziostation, Amin, Tokyo, Japan). We evaluated the original axial images (i.e., thin-slice maximum intensity projections and multiplanar reconstruction images orthogonal and parallel to the vessel centerline).

The presence or absence of distal coronary reperfusion on MDCT was defined as follows. When an IRA was not visualized on MDCT beyond the obstruction, coronary reperfusion was considered absent. When an IRA was continuously visualized from the ostium to the distal coronary artery, coronary reperfusion was considered present. The culprit lesion of STEMI was defined on MDCT as a site of total occlusion or the most severely narrowed lesion site in the IRA. The location of each culprit lesion is described according to the American Heart Association classification (14). Coronary segments were identified on the basis of the origin of side branches. We initially evaluated the Agatston calcium score, the location of the culprit lesion, and the presence or absence of distal reperfusion relative to the IRA that was determined by both the ECG and echocardiography findings. In patients with reperfusion on MDCT, the CT number in the middle of the contrast-enhanced coronary lumen on the cross-sectional images was determined at an apparently normal site (proximal site) within 5 mm proximal to the culprit lesion and at the most distal site (distal site) of the IRA visualized by MDCT with a ROI. The ROI size of each lesion depended on the judgment of experienced observers. The CT number was measured on 3 cross-sectional images at the proximal and distal sites of the IRA, and then we calculated the mean. As an index to differentiate TIMI flow grade 3 flow from ≤2, the distal/proximal CT number ratio was calculated by dividing the CT number of the coronary lumen at the distal site of the IRA by that at the proximal site. Vessel diameter was also measured at the proximal and distal sites. Residual percentage diameter stenosis of the culprit lesion was calculated with the luminal diameter at the maximal coronary stenosis and the mean luminal diameter at the proximal and distal reference sites. These parameters were measured 3 times, and the mean was calculated for analysis in the MDCT study.

Invasive coronary angiography. Emergency ICA proceeded immediately after MDCT in all patients via the femoral artery approach with a 5-F standard catheter and an INNOVA 2000 (GE Medical Systems, Waukesha, Wisconsin) instrument. All patients received intravenous heparin (5,000 U) and intracoronary isosorbide dinitrate (2 mg). Several views of the right and left coronary arteries were digitally acquired, and the minimal lumen diameter of the culprit lesion, the reference vessel diameter, and percentage diameter stenosis were quantified with a computer-assisted, automated edge-detection algorithm (Cardiac QCA, GE Medical Systems) with a 5-F catheter as the reference. Stenosis was evaluated from the worst view. Angiographic TIMI flow grade was evaluated with the initial coronary angiography procedure as described (1), and TIMI flow grades 2 or 3 were defined as the presence of distal coronary reperfusion. The TIMI or corrected TIMI frame count was measured in patients with TIMI flow grade 2 or 3 reperfusion as described (15). The degree of angiographic collateral circulation was determined with the Rentrop grading system (16).

Like the comparison of MDCT images between patients with TIMI flow grade 2 and 3 reperfusion, the coronary lumen visualized by ICA was densitometrically analyzed at the site proximal to the

JACC: CARDIOVASCULAR IMAGING, VOL. 4, NO. 2, 2011
FEBRUARY 2011:141–9

Table 1. Patient Characteristics

		TIMI Flow Grade Determined by ICA			
	Total (n = 87)	0 (n = 55)	1 (n = 3)	2 (n = 17)	3 (n = 12)
Age (yrs)	66 ± 12	68 ± 13	62 ± 25	67 ± 9	61 ± 11
Male/female (n)	57/30	33/22	2/1	13/4	9/3
Body mass index (kg/m^2)	23.8 ± 3.4	24.0 ± 3.9	25.0 ± 1.3	23.3 ± 2.2	23.7 ± 3.3
HR (beats/min)	76 ± 18	74 ± 18	80 ± 25	78 ± 18	86 ± 16
SBP (mm Hg)	138 ± 29	135 ± 31	119 ± 5	146 ± 21	148 ± 33
Hypertension (n)	46	32	1	6	7
Dyslipidemia (n)	44	28	0	8	8
Diabetes mellitus (n)	23	13	1	5	4
Current smoking (n)	44	26	2	9	7
Onset to door time (h)	4.2 ± 3.4	4.3 ± 3.6	2.7 ± 1.5	4.0 ± 3.5	4.3 ± 3.1
Door to CT time (min)	57 ± 14	58 ± 13	56 ± 9	56 ± 9	49 ± 16
CT to ICA time (min)	20 ± 5	20 ± 5	17 ± 5	21 ± 5	20 ± 4
Fibrinolysis (n)	12	5	2	1	4
Peak CPK (IU/l)	3,042 ± 2,308	3,726 ± 2,355*	1,568 ± 1,463	1,970 ± 1,903	1,998 ± 1,324
Q-wave infarction (n)	66	48	1	9	8
Time delay† to PCI (min)	20 ± 3	21 ± 3	19 ± 3	20 ± 3	19 ± 2
MDCT findings					
HR during scan (beats/min)	68 ± 12	68 ± 12	75 ± 18	63 ± 11*	73 ± 10
Delay since contrast injection (s)	23 ± 4	23 ± 4	21 ± 1	23 ± 4	24 ± 4
CS in IRA	159 ± 264	115 ± 152	269 ± 146*	345 ± 492*	52 ± 78
ICA findings					
IRA (n)					
RCA	38	29	2	4	3
LAD	32	16	0	11	5
Circumflex	17	10	1	2	4
Reference diameter (mm)	3.3 ± 0.6	3.2 ± 0.4	3.5 ± 0.8	3.5 ± 0.6	3.1 ± 0.4
MLD (mm)	0.1 ± 0.3	0*	0.1 ± 0.0*	0.2 ± 0.1*	0.7 ± 0.5
Diameter stenosis (%)	95 ± 11	100*	97 ± 2*	95 ± 5*	74 ± 19
TFC or CTFC	48 ± 25	—	—	62 ± 22*	29 ± 13
Collateral grade (n)					
0–1	68	36	3	17	12
2	14	14*	0	0	0
3	5	5*	0	0	0

*p < 0.05 versus TIMI flow grade 3. †Time elapsed before emergency coronary intervention due to MDCT scanning.
CPK = creatine phosphokinase; CS = calcium score; CT = computed tomography; CTFC = corrected TIMI frame count; HR = heart rate; ICA = invasive coronary angiography; IRA = infarct-related artery; LAD = left anterior descending coronary artery; MDCT = multidetector computed tomography; MLD = minimal lumen diameter; PCI = percutaneous coronary intervention; RCA = right coronary artery; SBP = systolic blood pressure; TFC = TIMI frame count; TIMI = Thrombolysis In Myocardial Infarction.

culprit lesion and at the distal site of the IRA in patients with TIMI flow grade 2 and 3 reperfusion, and the ratio of contrast opacification was calculated as in the MDCT study. Data were analyzed with an Advantage Workstation Volume Share (GE Medical Systems). Two independent and

Table 2. Findings of MDCT Versus TIMI Flow Grade Determined by ICA

		TIMI Flow Grade Determined by ICA			
MDCT Findings	Total (n = 87)	0 (n = 55)	1 (n = 3)	2 (n = 17)	3 (n = 12)
Visualized distal reperfusion (+)	31	2	1	16	12
Visualized distal reperfusion (−)	56	53	2	1	0
Reperfusion (+) and CT number ratio ≥0.54	13	1	0	1	11
Reperfusion (−) or CT number ratio <0.54	74	54	3	16	1

Abbreviations as in Table 1.

blinded observers reviewed the coronary angiography recordings.

Reproducibility. Two observers measured the CT number at the proximal and distal sites in all patients with TIMI flow grade 2 or 3 to determine interobserver variability. The same observers repeated the measurements to determine intraobserver variability.

Statistical analysis. Categorical data are presented as absolute values and ratios (%), and continuous variables are expressed as mean ± SD. The incidence of categorical variables was compared with the chi-square test, and continuous variables were compared with the Mann-Whitney *U* test. The CT number ratio used to indicate TIMI flow grade 3 was analyzed with receiver-operator characteristic (ROC) curves. We selected the closest point to the upper left corner on the ROC curve as optimal cutoff value. Comparisons of percentage diameter stenosis determined by MDCT and by quantitative coronary angiography were analyzed with the Spearman rank correlation coefficient and the Bland-Altman plot analysis. All data were statistically analyzed with Stat View software version 5.0 (SAS Institute, Inc., Cary, North Carolina). A p value of <0.05 was considered statistically significant.

RESULTS

Patient characteristics. Table 1 summarizes the profiles of the 87 patients. The TIMI reperfusion findings according to emergency ICA were flow grades 0, 1, 2, and 3 in 55 (63%), 3 (3%), 17 (20%), and 12 (14%) of the patients, respectively.

Evaluation of distal coronary reperfusion: 64-slice MDCT versus ICA. Contrast-enhanced 64-slice MDCT proceeded uneventfully with no complications in all 87 patients. The locations of culprit lesions determined by MDCT and by ICA coincided in 85 (98%) of the 87 patients. Visualized distal reperfusion was determined by MDCT in 31 (36%) of the 87 patients (Table 2). Of the 31 patients, 12 had TIMI flow grade 3 at the time of ICA, and 16 had TIMI flow grade 2; the remaining 3 had TIMI flow grade 0 or 1. Of the 56 patients without distal reperfusion determined by MDCT, 55 had TIMI flow grades 0 or 1, and 1 had TIMI flow grade 2 according to ICA. Therefore, the presence of coronary reperfusion with TIMI flow grades 2 and 3 on ICA was generally associated with distal coronary reperfusion visualized by MDCT. The sensitivity, specificity, and accuracy of a diagnosis of TIMI flow grade 2 or 3 coronary reperfusion on the basis of visualization of the IRA by MDCT were 97%, 95%, and 95%, respectively. However, a diagnosis of TIMI flow grade 3 by the same criteria was less effective, with sensitivity, specificity, and accuracy of 100%, 75%, and 78%, respectively.

Diagnosis of angiographic TIMI flow grade 3: 64-slice MDCT versus ICA. An analysis of the MDCT findings from patients with TIMI flow grade ≤2 or 3

Table 3. Comparison of MDCT Findings Between Patients With Angiographic TIMI Flow Grades ≤2 and 3

MDCT Findings	TIMI Flow Grade ≤2 by ICA (n = 19)	TIMI Flow Grade 3 by ICA (n = 12)	p Value
Culprit lesion			
Reference diameter (mm)	3.3 ± 0.6	3.0 ± 0.3	0.28
Minimal lumen diameter (mm)	0.57 ± 0.31	0.94 ± 0.34	0.007
Diameter stenosis (%)	85 ± 6	74 ± 11	0.01
Proximal site			
Vessel diameter (mm)	3.5 ± 0.6	3.3 ± 0.4	0.15
ROI size (mm^2)	0.55 ± 0.07	0.56 ± 0.07	0.67
CT numbers (HU)	414 ± 53	384 ± 58	0.17
Distal site			
Vessel diameter (mm)	0.8 ± 0.3	0.8 ± 0.3	0.63
ROI size (mm^2)	0.36 ± 0.06	0.37 ± 0.05	0.90
CT numbers (HU)	153 ± 44	249 ± 63	0.0007

HU = Hounsfield units; ROI = region of interest; other abbreviations as in Table 1.

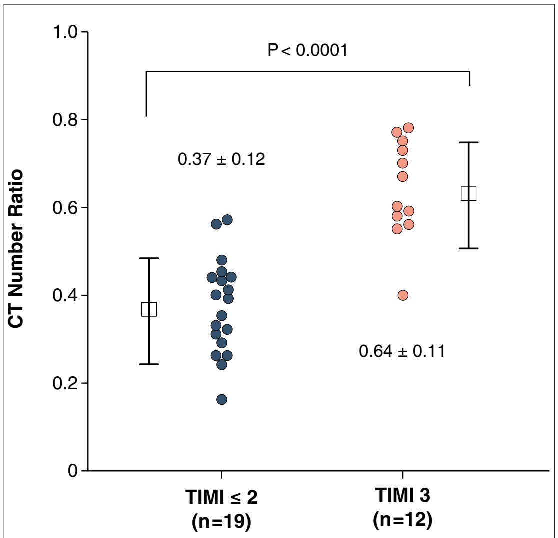

Figure 1. Differences in Distal/Proximal CT Number Ratios Between Patients With Distal Reperfusion Visualized by Coronary CT

Data are from patients with and without Thrombolysis In Myocardial Infarction (TIMI) flow grade 3 reperfusion. CT = computed tomography.

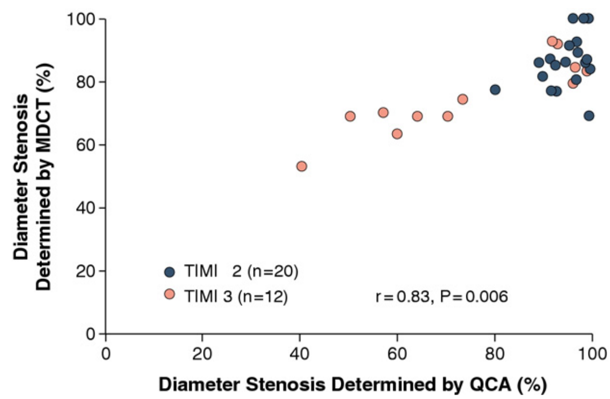

Figure 2. Correlation Between Percentage Diameter Stenosis of Culprit Lesions Determined by MDCT and QCA

MDCT = multidetector computed tomography; QCA = quantitative coronary angiography; TIMI = Thrombolysis In Myocardial Infarction.

(Table 3) revealed no significant difference between TIMI flow grade ≤2 and 3 regarding luminal CT number at the proximal site (414 ± 53 HU vs. 384 ± 58 HU; p = 0.17), but luminal CT number at the distal site was significantly higher in patients with TIMI flow grade 3 than with TIMI flow grade ≤2 (249 ± 63 HU vs. 153 ± 44 HU; p = 0.0007). Patients with TIMI flow grade 3 had a significantly higher CT number ratio than those with TIMI flow grade ≤2 (0.64 ± 0.11 vs. 0.37 ± 0.12; p < 0.0001) (Fig. 1). A luminal CT number ratio of 0.54 was selected on the basis of ROC curve analysis as the optimal cutoff value to differentiate TIMI flow grade 3 from TIMI flow grade ≤2 reperfusions. The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of a diagnosis of TIMI flow grade 3 on the basis of visualization of coronary reperfusion and a distal/proximal CT number ratio of ≥0.54 determined by MDCT were 92%, 97%, 85%, 99%, and 97%, respectively (Table 2).

Comparison of residual coronary stenosis: 64-slice MDCT versus ICA. Spearman correlation between residual percentage diameter stenosis determined by MDCT and by ICA was significant in 32 patients with TIMI flow grade 1 to 3 reperfusion determined by ICA (r = 0.83, p = 0.006) (Fig. 2). Bland-Altman analysis revealed a bias of +4.9% with 95% limit of agreement ranging from +1.2% to +8.6% (Fig. 3). Figure 4 shows representative MDCT images of patients with TIMI flow grades 0, 2, and 3.

Difference in luminal contrast opacification on ICA between TIMI flow grades 2 and 3 determined by densitometry. The ratio of pixels of the IRA determined by densitometry was significantly higher in patients with TIMI flow grade 2 than with TIMI flow grade 3 (n = 29, 1.6 ± 0.3 vs. 1.3 ± 0.4; p = 0.02), which is in accordance with the difference in the CT number ratio between the 2 flow grades evaluated by MDCT.

Reproducibility of measurements. The interobserver and intraobserver variability of the CT number at the proximal site was 11.8 ± 8.7 HU (2.9 ± 2.2% of the mean) and 10.0 ± 9.4 HU (2.5 ± 2.2% of the mean), respectively. These values at the distal site were 11.0 ± 13.5 HU (5.6 ± 5.0% of the mean) and 10.1 ± 7.4 HU (5.3 ± 3.1% of the mean), respectively.

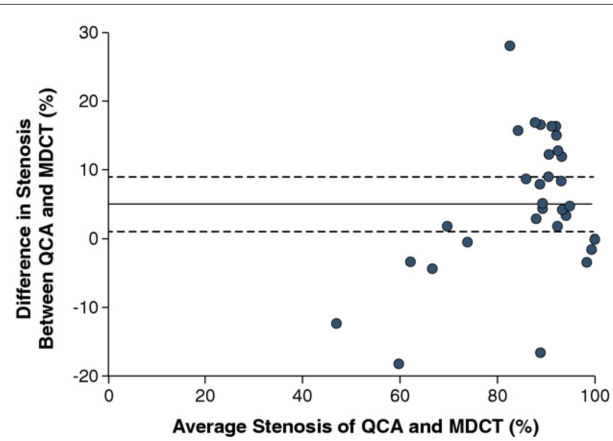

Figure 3. Bland Altman Analysis of Stenosis Grading With MDCT Versus QCA

Dashed lines indicate 95% confidence limits; **bold line**, bias. Abbreviations as in Figure 2.

DISCUSSION

The present study demonstrated that 64-slice MDCT enables the noninvasive differentiation of angiographic TIMI flow grade 3 from TIMI flow grade ≤2 coronary reperfusion in patients with STEMI. Coronary MDCT provides coronary artery images from which the presence or absence of coronary reperfusion in patients soon after STEMI can be evaluated. The presence of distal coronary reperfusion on MDCT generally indicates TIMI flow grade 2 or 3 and therefore is not specific to TIMI flow grade 3. However, we found that 64-slice MDCT can visualize differences in luminal contrast enhancement of the distal IRA between patients with TIMI flow grades 2 and 3 reperfusion. Consequently, a distal/proximal CT number ratio of ≥0.54 determined by MDCT generally indicates

TIMI flow grade 3, whereas a CT number ratio of <0.54 generally indicates TIMI flow grade 0 to 2. Thus, differences in the CT number ratio of the vessel lumen in the IRA enable the differentiation of TIMI coronary reperfusion grade 3 from ≤2.

Several coronary MDCT studies (6,17) with comparable findings have shown that MDCT can correctly evaluate total occlusion and detect significant coronary artery stenosis. However, the presence of excellent coronary collateral flow comes into question when evaluating coronary reperfusion by coronary MDCT. Two of our patients were misidentified as having distal reperfusion on MDCT, although ICA showed total occlusion, because the IRA distal to the total occlusion site had excellent anterograde and retrograde collateral flow. Thus, some discrepancies in the diagnosis of coronary reperfusion were evident between MDCT and subsequent ICA. These discrepancies might be associated with technical difficulties encountered when visualizing coronary artery images from 64-slice MDCT. Another possibility is the dynamic nature of coronary reperfusion (18). The culprit lesion might have become recanalized or reoccluded during the interval between MDCT and ICA.

Angiographic TIMI flow grade 2 after PCI is caused by microvascular dysfunction secondary to distal embolization of thrombus/plaque components after mechanical dilation (19) or by incomplete coronary dilation by PCI (12). In contrast, TIMI flow grade before PCI depends on the severity of residual stenosis in the culprit lesion. A TIMI flow grade 2 before PCI is caused by low coronary blood flow due to severe residual stenosis and not by microvascular dysfunction (5,11,12). In comparison, coronary blood flow in TIMI flow grade 3 and less residual stenosis are preserved or even increased due to reactive hyperemia after reperfusion (5,11,12). The degree of residual stenosis in the epicardial coronary artery affects the volume of contrast medium flowing in the artery distal to the coronary stenosis; differences among residual stenoses result in differences in contrast opacification of the coronary lumen in the distal IRA of patients with TIMI flow grades 2 and 3. Pathophysiological differences in coronary blood flow can be visualized with 64-slice MDCT, which allows the noninvasive differentiation of TIMI flow grades 3 and 2.

When fibrinolysis and not primary PCI is chosen as the initial reperfusion therapy in patients with STEMI, the American College of Cardiology/American Heart Association guidelines (20) recom-

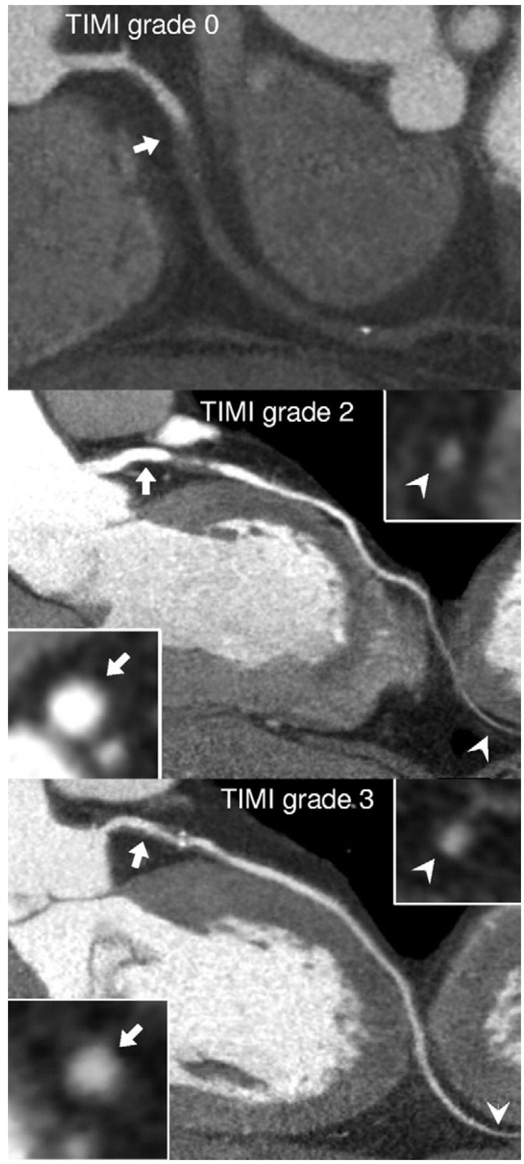

Figure 4. Curved Multiplanar CT Reformations and Short-Axis Cross-Sectional Views of Infarct-Related Arteries in Patients With TIMI Flow Grades 0, 2, and 3

(Top panel) coronary CT angiography shows total occlusion at proximal portion of right coronary artery **(arrow)**. (**Middle panel)** infarct-related artery reperfuses proximal portion of left anterior descending artery (LAD). Contrast medium has reached distal LAD site. The CT numbers at the proximal **(arrow)** and distal **(arrowhead)** sites were 426 and 130 HU, respectively, and CT number ratio was 0.31. (**Bottom panel)** coronary CT shows coronary reperfusion at proximal portion of LAD. The CT numbers at proximal **(arrow)** and distal **(arrowhead)** sites were 363 and 279 HU, respectively, and CT number ratio was 0.77. CT = computed tomography; HU = Hounsfield units; TIMI = Thrombolysis In Myocardial Infarction.

mended that high-risk patients be transferred immediately to a PCI-capable facility for diagnostic ICA and consideration of PCI, and if not high risk, the patients might be moved to a PCI-capable facility after fibrinolysis or might be observed in the initial facility. Among such non–high-risk patients treated with fibrinolysis at a hospital without a catheterization laboratory, 64-slice MDCT provides an effective option to identify those who should be transferred to a PCI-capable facility to undergo rescue PCI. This is because coronary MDCT visualization of the IRA enables accurate, noninvasive differentiation of angiographic TIMI flow grade 3 from TIMI flow grade ≤2 coronary reperfusion in patients soon after STEMI.

Study limitations. The limitations of coronary MDCT with 64-slice scanners include radiation exposure and the use of contrast agent. An additional limitation to that conferred by the presence of calcium and rapid coronary motion is that patients with severe arrhythmias including atrial fibrillation and renal insufficiency or those with contraindications to iodinated contrast agent cannot be scanned. Therefore, although coronary MDCT is superior to conventional noninvasive tools with respect to the appropriate identification of TIMI flow grade 3 after STEMI, it is not suitable for all candidates.

Coronary arteries can currently be evaluated by 64-slice MDCT within approximately 40 min. Next-generation MDCT equipment with more detector rows (3,20) and workstation advances should reduce the amount of time required from coronary artery scanning to visualization, lower the amount of required contrast medium and radiation dose (21), and thus expand the feasibility of coronary MDCT to coronary artery evaluation in patients with STEMI.

The present investigation was a single-center study of a relatively small patient cohort. Future application of the present methodology would benefit from analyzing data from a large patient population. In the present study, a ROI size for the measurement of the CT number depended on the judgment of experienced observers. Consequently, a ROI size was approximately one-fifteenth and two-thirds of the contrast-enhanced coronary lumen area at the proximal and distal sites of the lesion, respectively, and we demonstrated the reproducibility of CT number measured by the ROI. However, a ROI size has influence on the CT number that is measured. In addition, we only included patients with a first STEMI that had developed within 12 h and who potentially required emergency PCI. The preservation of distal coronary blood flow might be related to a hyperemic response after reperfusion, which can potentially last for several hours (22). Furthermore, collateral circulation might develop after STEMI. Therefore, whether these results can be generalized to those who present with acute myocardial infarction of ≥12 h from onset remains unknown.

Finally, MDCT scanning before PCI is not recommended for routine diagnosis, and a clinical benefit has not yet been demonstrated. The possibility of a worse outcome due to the time delay and exposure to contrast, although not evident from this study, cannot be excluded.

Acknowledgments

The authors thank the staff of the emergency department at Kagoshima City Hospital, the CT laboratory, and the cardiac catheterization laboratory for their valuable assistance.

Reprint requests and correspondence: Dr. Souki Lee, Department of Cardiology, Kagoshima City Hospital, 20-17 Kajiya, Kagoshima City 892-8580, Japan. *E-mail: lee@ml.kch.kagoshima.kagoshima.jp.*

REFERENCES

1. The TIMI Study Group. The thrombolysis in myocardial infarction (TIMI) trial: phase I findings. N Engl J Med 1985;312:932–6.
2. Anderson JL, Karagounis LA, Becker LC, et al. TIMI perfusion grade 3 but not grade 2 results in improved outcome after thrombolysis for myocardial infarction: ventriculographic, enzymatic, and electrocardiographic evidence from the TEAM-3 study. Circulation 1993;87:1829–39.
3. de Lemos JA, Antman EM, Giugliano RP, et al., for the Thrombolysis in Myocardial Infarction (TIMI) 14 investigators. ST-segment resolution and infarct-related artery patency and flow after thrombolytic therapy. Am J Cardiol 2000;85:299–304.
4. Tanasijevic MJ, Cannon CP, Antman EM, et al. Myoglobin, creatine-kinase-MB and cardiac Troponin-I 60-minute ratios predict infarct-related artery patency after thrombolysis for acute myocardial infarction. Results from the Thrombolysis in Myocardial Infarction study (TIMI) 10B. J Am Coll Cardiol 1993;34:739–47.
5. Lee S, Ostuji Y, Minagoe S, et al. Noninvasive evaluation of coronary reperfusion by transthoracic Doppler echocardiography in patients with anterior acute myocardial infarction before coronary intervention. Circulation 2003;108:2763–8.
6. Hoffmann MH, Shi H, Schmitz BL, et al. Noninvasive coronary angiography with multislice computed tomography. JAMA 2005;293:2471–8.

7. Hoffmann U, Nagurney JT, Moselewski F, et al. Coronary multidetector computed tomography in the assessment of patients with acute chest pain. Circulation 2006;114:2251–60.
8. Rubinshtein R, Halon DA, Gaspar T, et al. Usefulness of 64-slice cardiac computed tomographic angiography for diagnosing acute coronary syndromes and predicting clinical outcome in emergency department patients with chest pain of uncertain origin. Circulation 2007;115:1762–8.
9. Henneman MM, Schuijf JD, Pundziute G, et al. Noninvasive evaluation with multislice computed tomography in suspected acute coronary syndrome. J Am Coll Cardiol 2008;52:216–22.
10. Miller JM, Rochitte CE, Dewey M, et al. Diagnostic performance of coronary angiography by 64-row CT. N Engl J Med 2008;359:2324–36.
11. Kern MJ, Moore JA, Aguirre FV, et al. Determination of angiographic (TIMI grade) blood flow by intracoronary Doppler flow velocity during acute myocardial infarction. Circulation 1996;94:1545–52.
12. Akasaka T, Yoshida K, Kawamoto T, et al. Relation of phasic coronary flow velocity characteristics with TIMI perfusion grade and myocardial recovery after primary percutaneous transluminal coronary angioplasty and rescue stenting. Circulation 2000;101:2361–7.
13. Killip T, Kimball JT. Treatment of myocardial infarction in a coronary care unit. Am J Cardiol 1967;20:457–64.
14. Austen WG, Edwards JE, Frye RL, et al., for the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. A reporting system on patients evaluated for coronary artery disease. Circulation 1975;51 Suppl:5–40.
15. Gibson CM, Cannon CO, Daley WL, et al. TIMI frame count: a quantitative method of assessing coronary artery flow. Circulation 1996;93:879–88.
16. Rentrop KP, Cohen M, Blanke H, Phillips RA. Changes in collateral channel filling immediately after controlled coronary artery occlusion by an angioplasty balloon in human subjects. J Am Coll Cardiol 1985;5:587–92.
17. Chiou KR, Wu MT, Hsiao SH, et al. Safety and accuracy of multidetector row computed tomography for early assessment of residual stenosis of the infracted-related artery and the number of diseased vessels after acute myocardial infarction. Am Heart J 2005;149:701–8.
18. Hackett D, Davies G, Chierchia S, Maseri A. Intermittent coronary occlusion in acute myocardial infarction. Value of combined thrombolytic and vasodilator therapy. N Engl J Med 1987;317:1055–9.
19. Iwakura K, Ito H, Takiuchi S, et al. Alternation in the coronary blood flow velocity pattern in patients with no reflow and reperfused acute myocardial infarction. Circulation 1996;94:1269–75.
20. Kushner FG, Hand M, Smith SC Jr., et al. 2009 focused updates: ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction (updating the 2004 guideline and 2007 focused update). J Am Coll Cardiol 2009;54:2205–41.
21. Rybicki FJ, Otero HJ, Steigner ML, et al. Initial evaluation of coronary images from 320-detector row computed tomography. Int J Cardiovasc Imaging 2008;24:535–46.
22. Heyndrickx GR, Amano J, Patrick TA, et al. Effects of coronary artery reperfusion on regional myocardial blood flow and function in conscious baboons. Circulation 1985;71:1029–37.

Key Words: diagnosis ■ myocardial infarction ■ reperfusion ■ tomography.